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ROBOTIC EXOSKELETONS: A REVIEW ON DEVELOPMENT

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ABSTRACT

Robotic exoskeletons are one of the extremely vigorous zones in recent robotic exploration as it is an emerging product which fulfils different applications in society. In the last six decades, many research works have been carried out to escalate the staging of exoskeletons thus flourish them to nearly mercenary products. This paper briefly studious the current progress of the robotic exoskeleton structures and furnishes awareness into the modern evolution in robotic exoskeletons along with their requisitions and also provides detailed information regarding required parameters to be concentrated for designing and fabrication of the robotic exoskeleton. In the brief appraisal it is attentive to classify the concise history, need, classification, applications, confronts facing by them, design considerations and technology required to understand and design, Software's used for designing and simulation of the exoskeletons. Further, some concluding remarks are perceived which could be useful for ensuing work.

KEYWORDS: Exoskeletons, Robot, Healthcare, Military, Classifications & Development

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Original Article

INTRODUCTION

In usual exoskeletons are the exterior skeletons that support and preserves an animal body in contrast to the internal skeleton; a developed Exoskeleton is a wearable robotic manipulator that can be worn by a human with man-machine intelligence to boostup their strength or restore movement by assisting the abled or non-abled wearer to perform human tasks [1] [2].

Improvements are essentially being compelled by two claims: to escalate the energy and load managing competencies of the capable bodied and to reinstate or enrich the motion and energy of individuals enduring from infirmities or mutilations [3]. Due to the close contact between the user and the exoskeleton, these devices need to be instinctively in harmony with humanoid, capable to carefully transfer in recital with the user without prohibiting or withstanding change [4].

With the intention to be serviceable and acquire by societies, these exoskeletons should accomplish certain potentialities and recital attributes together with the following:

- Human Act Intensification: The exoskeleton must rise wearer's asset, durability and/or speed empowering

them to execute responsibilities that they are not able to execute them previously.

- Low Impedance: The exoskeleton would not disrupt the consumer's usual motion.
- Natural Interface: The exoskeletons have to yield a natural, instinctive, crystalline interface such that the user senses as if the exoskeleton is a real addition of his/her bodies rather than somewhat that the user is handling.
- Long Life: The exoskeleton must ensure adequate span of use flanked by energy system recharge also a fast and effortless recharging method.
- Comfortable: The exoskeletons ought to be congenial and secure to wear and comfortable to start and stop[5].

CONCEPT OF EXOSKELETON

The perception of an exoskeleton structure in ecology is able to be recognized as an addition of the external skeleton, in which the exoskeleton is an external mask on a living being which acts as armour support, enrichment of energy or feeling and data inclusion [6]. The finest instance of an exoskeleton in ecology is a shell of a crustaceans such as crabs which assists not only as a protection upon the body, on the other hand also acts as a surface cover intended for muscle joining, a water-resistant barrier against withering, and a sensual interaction with the environments. In robotics, an exoskeleton is mostly a wearable piece of equipment which comprises of an operating system with sensors and actuators whose links and couplings corresponding to those of the human frame.

While a mechanized exoskeleton is put on by the person the corporal connection among the consumer and the exoskeleton tolerates direct transmission of motorised power and information signals. In employing the robotic exoskeleton for regular movement assist, the consumer allows the control signal for the exoskeleton, whereas the actuator of the exoskeleton supplies maximum power essential for executing the task. Thus capability of the robot consumer and the intelligence of the robot is get boosted for the day-to-day action contribution.

REVIEW OF ROBOTIC EXOSKELETONS

Historical Background

The proposal of employing exoskeletons to intensify human locomotion accomplishments dates back to 1890, Nicholas Yagn a Russian scientist has developed an exoskeleton like device in 1890 which was a set of walking, running and jumping assisted apparatus and to perform these operations it requires compressed gas bags which stores energy that assist with movements, although it entails human power as it is passive in operation [7].

Leslie C. Kelly a scientist of the United States in 1917 has developed contrived ligaments acting in, similar to the wearer's ligament fluctuations. With the pedometer, energy could be originated aside from the user.

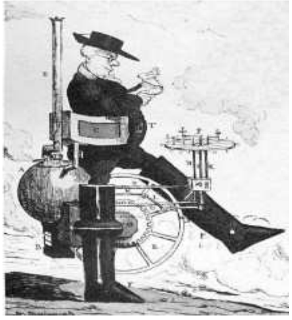

Figure 1: Pedometer developed by Leslie C. Kelly [31].

General Electric Research has built a full-body power-driven exoskeleton model 'Hardiman' in collaboration with scholars at Cornell University, also with pecuniary provision from the U. S. Office of Naval Research, in late 1960's. The exoskeleton was an massive electrically motorized and hydraulically mechanized device which weighs 680 kg and have 30 DOFs, comprising modules for boosting the potency with a factor of 25 to the arms which comprises hands but excepting wrists and legs of the user. But this exoskeleton has failed due to several reasons such as slow walking speed: 0.76 m/s, as it is a master slave system, the response time due to multiple physical layers is high and Testing of Hardiman (full exoskeleton) results a violent un-Controlled motion. Further concentrated on one arm even it could lift load of 340 kg. The practical Uses are limited without getting all the Components to work together [8].

Figure 2: Hardiman [1]

Beginning of development of humanoid robotics is coincided with the beginning of the world's first active exoskeleton at Mihailo Pupin institute in 1969, under the guidance of prof. Vukobratovic. They legged locomotion system along with theory of the systems in frame of active exoskeletons and said that active exoskeletons are predecessors of modern high performance humanoid robots.

The primary active exoskeleton has been introduced with 3 DOFs for each leg in 1970. This exoskeleton is recognized as the fractional exoskeleton as it consists of seven pneumatic actuators and fourteen electromagnetic solenoid stopcocks. The exoskeleton allowed a paraplegic to walk, however was not capable to furnish strenuous firmness. So that it fails in preventing the wearer from falling sideways. And in 1972 the most complete prosperous version of active exoskeleton was developed and tested at the Belgrade Orthopedic clinic, which is used for paraplegics and similar disabled persons [9].

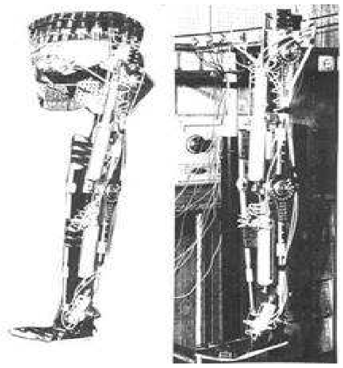

Figure 3: Successful Version of Active Exoskeleton Developed by Prof. Vukobratovic [1].

In 1978, the 'active suit' was developed which was an independent, microcomputer supervised active exoskeleton authorized by servo electric drives. This is used to engage the hip joint and mounted for the knee joint. The device was authorized by nickel-cadmium batteries and regulated by a microprocessor. The exoskeleton girdle was fabricated with resilient sensed and weightless composite stiffeners. The exoskeleton was trailed by a person with muscular disabilities. The person was capable to accommodate to the suit briefly and uses it with no problem [10].

In 1986, Monty Reed a United States army ranger who had affected his back in parachute tragedy, during the stage of recovery he spent time on referring Robert Heinlein’s science friction novel and developed an exoskeleton prototype, further developed mobile infantry power suits called the LIFESUIT. Later he conveyed his ideas to the military and LIFESUIT-1 was developed in 2001 and he goes on developing some of the achievements in development are as follows. TheLS-6 have recorded and play backed a human gait in 2003, LS-12 has been victorious in a foot race in 2005 and has land speed distance record for walking in robot suits.

Figure 4: Active Life Suit [1]

Need of Exoskeletons

Exoskeletons are widely used in different applications and the main function of the exoskeletons in any application is to provide Protection, Support and Enhancement of human power etc. [11]. These are the three major parameters that the exoskeletons are concentrating.

Among these speed is one of the parameter that the exoskeleton need to be concentrated but till today there is a lag in the development of the exoskeletons that are concentrating on the speed. At present the researchers are taken it as a challenge and concentrating on the development of speed in exoskeletons to the extent.

Classification of Exoskeletons

In recent years, researches into exoskeleton systems have become a subject undergoing intense study. Various corporations all over the globe have originated majestic exoskeletons for potency amplification where these diverge crucially in performance and in the technology used. So the classification of the exoskeletons depends on the different parameters that are required for the functioning of exoskeleton and these are narrated as follows.

These are four types of exoskeletons; lower limb exoskeletons (LEEs), upper limb exoskeletons (UEEs), full body exoskeletons, and specific joint support exoskeletons [12] [13] which are classified according to support given by exoskeletons to locations of human anatomy. Further, these exoskeletons are listed into three essential applications as they are Gait recovery, human motion support, and human strength enhancement. Here upper extremities are mainly fascinated on arms and torso, further split in to particular areas some exoskeletons focus on wrist, fingers and some on shoulder, elbow joints. And lower extremities are mainly fascinated on legs, further divided in to hip, knee or ankle or combination of any two or all the three.

Figure 5: LEE

Figure 6: UEE [12] [13]

Based on the usage of power exoskeleton can be widely listed into four groups: passive exoskeleton, pseudo-passive exoskeletons, powered exoskeletons and hybrid exoskeletons where powered and hybrid are undertaken as active devices [14] [15].

Passive exoskeletons do not demand any energy resource and usually comprise of springs, linkages and dampers Passive exoskeletons are generally light in weight, but due to the absence of power supply and electronics, their manageability is bounded [16]. And these passive exoskeletons are generally employed for a) Weight re-distribution: springs and fastening mechanisms transfer the load of an article round about the person to the land, b) energy capture: ankle spring-clutch exoskeletons have been exposed to enhance sauntering performance, whereas spring-dynamo knee exoskeletons are utilized to power-up a battery, c) Dampening: some spring-damper or spring passive exoskeletons have been intended as shock absorbers or vibration diminishes. High speed ski Mojo is an example of shock absorber and small high speed boat marine mojo is an example of vibration reducers. d) Locking: some passive exoskeletons permit the consumer to be seated in the same position for a long-lasting time.

Figure 7: Spring Clutch Exoskeleton, Spring Dynamo Knee Exoskeleton of Energy Capture [1]

Figure 8: Ski Mojo, Marine Mojo Shock Absorbers and Vibration Reducers [16]

Figure 9: Locking Device [37]

Quasi-Passive exoskeletons consist of batteries, measuring devices and extra electronics, however they are not employed to actuate. The greatest model of a quasi-passive exoskeleton is the C-Brace which is developed by Otto bock, where its electronics are used to supervise a semi-active dashpot in the knees. The C-Brace on the other hand it reveals, reduce the oscillation of the limb and locks as leg has been subjected to the situation in the locomotion phase as resolved by the incorporated sensors.

Figure 10: C-Brace [33]

A powered exoskeleton is an architectural exterior structure with joints and links is in contact to those of human anatomy which are powered by an arrangement of power-driven motors, hydraulics, pneumatics, levers or a grouping of technologies that permits for extremity travel with improved potency and permanence. Further, these are again classified into a) Static exoskeleton: The actuators must captivate the whole time in order for the device to sustain its shape. b) Dynamic exoskeleton: Actuators need not to be captivated for whole time and the system can be often high energy efficient. These types of exoskeletons are classified beyond what they are proposed to do [17]. As the powered exoskeletons use all the drives so as it can be computerized therefore it is considered as immoderate.

Hybrid exoskeletons are wearable's consists of sensors and controllers as a power-driven exoskeleton but employees FES (functional electrical stimulation) of the muscles as operators. Functional electrical stimulation (FES) is a manner that uses little energy electrical pulses to produce body actions artificially in persons who have been paralyzed by the damage to the central nervous system (CNS).

Figure 11: Hybrid Exoskeletons [32]

Based on flexibility the exoskeletons are categorized into three types they are a) Fixed**:** The machine is fastened, adhere to a wall, bracket or dangle from the space by a rigid hanger. b) Supported: Here the exoskeleton is adhere to an overhead rail, is carried by a skeleton in action or in certain circumstances, bared by an adjoining gyrated robot. These alignments agree for the controllers, massive motors and batteries to be assisted while still allowing adaptability to exoskeleton consumer. c) Mobile: Exoskeleton has the moving nature i. e. the driver and exoskeleton can move around voluntarily [18].

Figure 12: Fixed, Supported, Mobile Exoskeletons [34], [35]

Based on the controlling these exoskeletons are classified as a)Buttons or control panels: The exoskeleton is situated at various preordained modes and the command panel need not have to be on the exoskeleton, as shown in fig 13. b) Mind-controlled: Using an electrode skull cap the whole exoskeleton is controlled According to its predetermined applications. c)Sensors: present exoskeletons models can have as many as distinct sensors incorporated with that to supervise tilting, pressure, gyration, turning force and can acquire nerve motions in the arms and legs d) No control: few

inert exoskeletons didn’t have any switches or control knobs [19].

Figure 13: Button Controlled, Mind Controlled Exoskeletons [36]

Based on the materials used for construction the exoskeletons are categorized into two types they are a) Exoskeletons manufactured by rigid substances such as carbon fiber or metals. b) Exoskeletons manufactured by flexible materials in the complete creation (soft exoskeleton or exo-suit) [20].

Applications of Exoskeletons

Exoskeletons have a wide range of applications and they are globally trended in four different fields of applications and are named along with their classifications as follows

- **Medical**

It is one of the foremost area for exoskeleton which have plenty of applications such as enrichment of accuracy at the time of surgery, used to facilitate the nurses to transfer heavy patients, also applied in the field of rehabilitation & physiotherapy of stroke or spinal cord damaged patients, Individuals with muscular disorders and more neuromuscular disabilities uses the exoskeletons to enhance their muscle power. And haptic feedback is the most trending research area where it is needed in surgical robots i. e. provided by haptic devices (exoskeletons) where the device interface with the doctor through a feel of touch as he directs the robot from a distinct solace that may be situated in an isolated location.

At present there are ‘43’ medical exoskeletons divided into ‘6’ categories and are followed as a) Stationary lower body exoskeletons – 5 b) Stationary upper body – arm & wrist exoskeletons for rehabilitation – 7 c) Stationary upper body hand exoskeletons for rehabilitation – 3 d) Mobile upper body exoskeletons for rehabilitation & augmentation – 7 e) Mobile lower body – rehabilitation exoskeletons – 14 f) Mobile lower body – augmentation exoskeletons – 7 [21] [22].

- **Military**

The demand of an exoskeleton in military have been expanding from day to day and the major application is to decrease fatigue and increase productivity by empowering a soldier while running or mounting stairs or walking for long distance and used to transfer heavier armor and weapons.

At present there are ‘19’ military exoskeletons divided in to ‘5’ categories and are followed as a) Full body military exoskeletons – 2 b) Lowered body powered military exoskeletons – 11 c) Passive military exoskeletons – 3 d) Energy scavenging military exoskeletons – 2 e) Stationary military exoskeleton – 1[23].

- **Industrial**

Exoskeletons also have broad range of requisitions at construction sites, graving docks, factories, storehouses etc.

There are ‘22’ exoskeletons divided in to ‘6’ categories they are a) Tool holding exoskeletons – 5 b) Chair less

chairs – 3 c) Back support – 6 d) Powered gloves – 2 e) Full body power suits – 5 f) Super numeracy robotic arms – 1.

- **Civilian**

In civilian areas, exoskeletons are used to help firefighters and other workers who are employed to work in dangerous environments.

Challenges Facing by Present Exoskeleton

The main challenges for the growth of robotic exoskeleton devices are the inaccessibility of appropriate accessory resources. Current actuating methodology and power broad cast methodology are not in a suitable circumstance to build up an impeccable precise robotic exoskeleton system. Here the "best robotic exoskeleton system" is a device which assists the user to recover his/her movements or to activate other devices without causing any inconvenience to users. The robot must not add intolerable mass for the user. The power broadcast methodologies with extreme transmission effectiveness and least friction are essential for the exoskeleton devices to be precise. Furthermore the back driveable capacity of the broadcast is also crucial for such devices to abolish conceivable discomfort to the user. Certain foremost confronts facing by the exoskeletons are Bulky in structure & Heavy Weight, Difficulties in wearing specially for people with disability. Huge power consumption & Battery back-up problem (especially in powered exoskeletons), highly expensive for common people, limitations on the performance of the available exoskeletons, Increase in speed – current exoskeletons does not concentrate on the wearers speed it just concentrate on the strength, Materials – very few materials are suitable for manufacturing in regards with weight/strength wise, Fabrication, Control – sudden involuntary or unplanned movements could result in serious injuries. These may happen by lagging of system functioning or improper design of safety protocols [24] [25].

Design Considerations

There are different parameters that are needed to be concentrated while designing the exoskeletons and the parameters that are needed to be undertaken are wear-ability, portability of the exoskeletons, efficient and long-lasting power supply, to accomplish a smooth human machine interface in various phases of gait sequence at the interaction point. Mass/inertia: Low mass/inertia also offers advantage in terms of safety, which is the primary requirement for any device directly attached to the human wearer, cost, Performance with ergonomics and consolation capability with the provision of the kinaesthetic force feedback for a wearer [26] [27].

Technology Required for Exoskeleton

So to understand the concept of the exoskeletons some of the basic fundamentals of different domain knowledge have been required among those Electronics, Mechanics, Bionics, Materials, Artificial intelligence and Control are the major domain knowledge's required to understand, design and fabrication of exoskeletons [28].

Software's used for Designing and Simulation

Before fabrication or manufacturing of any product it must undergo analysis of working conditions under virtual domains so that the final product can be fabricated easily without undergoing failures and so for designing, simulation and analysis of the exoskeletons MATLAB, Parametric 3D – Modeling software's (solid works, Ansys, Catia Adams) are used [29] [30].

CONCLUSIONS AND SCOPE FOR FURTHER WORK

A decent study on different parameters of the exoskeletons has made successfully, further concluded that these exoskeletons have wide range of applications in the real world so there is a huge requisite for the development of exoskeletons to solve any of the hazardous societal problems but for design or fabrication of any exoskeleton many parameters in distant areas have to be considered based on the application of exoskeleton which is going to be proposed for manufacturing.

Further current robotic exoskeletons usually cause inconvenience to the consumer, specifically while they carry it for everyday actions. Accordingly, the devices must be enriched to consume it for regular happenings by restricting any uneasiness. Moreover the creator must not take only the exterior structural characteristics of humanoid into account but also the functional requirement of the consumers. Meanwhile maximum of these robotic exoskeleton systems are proposed to be consumed for everyday actions they would be more moveable, stylish and lissom in the time ahead. To improve such class of devices, the trustworthiness, transferability and mass of robot, back driveable capability of its actuators need to be enhanced. Current actuators are weighty at sometimes with restricted power and torque, noisy at times and abnormal in structural frames which have an effect on structure of robotic exoskeleton. The operating methodology must be enhanced to improve tiny sized, high enduring and sophisticated operational actuators for these robots. Back driveable ability of the broadcast is necessary in robotic exoskeleton to remove uneasiness to the consumers. A high proficient back-drivable system must be essential for the devices in the future.

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